Development of Hydraulic Power Steering (HPS) System for Large Vehicles

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In accordance with recent increases in crude oil prices and the need to promote environmental protection, power steering systems have been changing from hydraulically assisted types to electrically assisted types because of the latter's ability to improve fuel efficiency. However, it is believed that the demand for hydraulic steering systems for large vehicles requiring high strength and high output will continue.

This report describes the development of an optimal hydraulic power steering system for large vehicles.

Key Words: *hydraulic power steering system, high output, large vehicle, improved fuel efficiency, high pressure, high flow rate*

1. Introduction

In recent years, hybrid vehicles and electric vehicles (EV) have been increasingly introduced due to the rapid rise of crude oil prices and out of consideration for the natural environment. In accordance with these trends, hydraulic power steering systems (HPS systems), which have an adverse influence on fuel consumption (because they are engine-driven), are being rapidly substituted by electric power steering (EPS) systems, which have no adverse influence on fuel consumption (because they are not engine-driven).

However, EPS systems currently can be used only on passenger cars. For application on large vehicles such as recreational vehicles (RV) or pickup trucks, such technical difficulties as cost reduction, higher strength and higher output must be resolved. Currently it is very difficult to apply EPS systems on such large vehicles. In the North American market, the demand for large vehicles is high. As shown in **Fig. 1**, sales of large vehicles was higher than sales of passenger cars in 2004. Thus, it is believed that the demand for HPS systems mainly for large vehicles will continue.

In order to respond to this situation, a new HPS system optimal for large vehicles has been developed and is introduced hereunder.

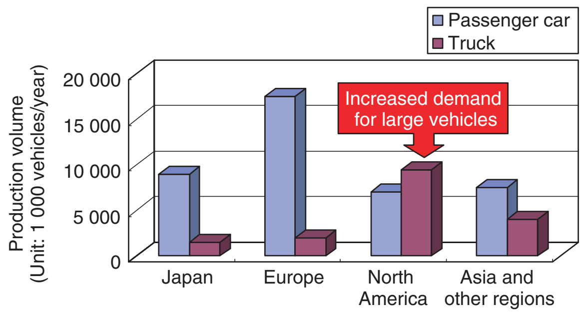

Fig. 1 Passenger car and truck markets of the world

2. Structure of HPS System

An HPS system is composed of a steering gear (PS gear), a vane pump (PS pump), a reservoir tank, and piping (PS piping) connecting these parts. There are two types of PS gears: rack & pinion type and ball screw type. The PS gear addressed in this report is a rack & pinion type steering gear. **Figure 2** shows the outline of this HPS system.

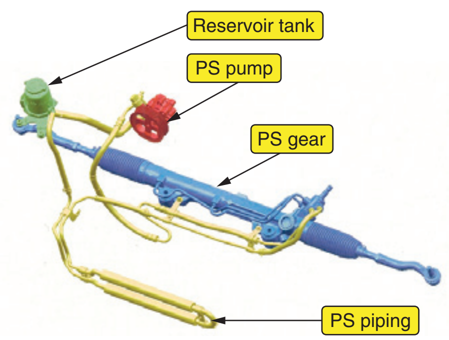

Fig. 2 Structure of HPS system

3. Objective of Development

A large vehicle has the following two characteristics.
· Large front axle load
· Large-displacement engine

Regarding the former, a PS gear with high strength and high output is required, and regarding the latter, a PS gear that can operate with a low-idling engine (for improved fuel efficiency) is required. To provide high strength, a large PS gear is required, and to provide high output, an increased pressure-receiving area of the cylinder and higher pressure are required. As a countermeasure for deteriorated steering followability due to the increased pressure-receiving area of the cylinder, a higher flow rate is required. As a countermeasure for the deteriorated supply flow rate from the PS pump caused by the above-mentioned low engine idling speed and to achieve the high flow rate required for high output, the supply flow rate per rotation (theoretical discharge flow rate) must be increased to achieve a higher capacity. However, realization of these requirements is not easy, and there are trade-offs for each as shown hereafter.

· Larger PS gear: Increase of weight
Increase of cost
· Increased cylinder pressure-receiving area:
Deterioration of steering followability
Increase of system oil quantity
· High pressure, high flow rate, and high capacity:
Oil temperature rise in the system
Deterioration of flow noise
Increase of pressure loss

For a large-vehicle HPS system, it is most important to solve the above trade-offs. In our development work this time, we selected the following six items as development focuses.

(1) Friction-welded rack bar
(2) High flow rate valve
(3) High capacity pump
(4) Variable flow controlled pump
(5) Finned cooler piping
(6) High capacity and high strength reservoir tank

Figure 3 shows large vehicle characteristics, HPS system requirements, trade-offs related to these requirements, and solutions for them.

4. Details of Development Items

Details regarding the development focuses listed in section **3** above and results are described hereafter.

4. 1 Friction-Welded Rack Bar

The rack bar is a PS gear part having the function of converting rotational force received from the steering wheel (via the pinion gear) to axial force and transmitting this force to the tires along with a bypass function by which air pressure in the sealed space divided by the cylinder section is uniformly maintained. **Figure 4** shows the rack bar in a PS gear. The structure is composed of a rack section (rack part) that engages with the pinion and a rod part supporting the hydraulic piston.

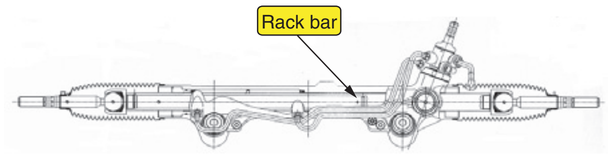

Fig. 4 Rack bar in PS gear

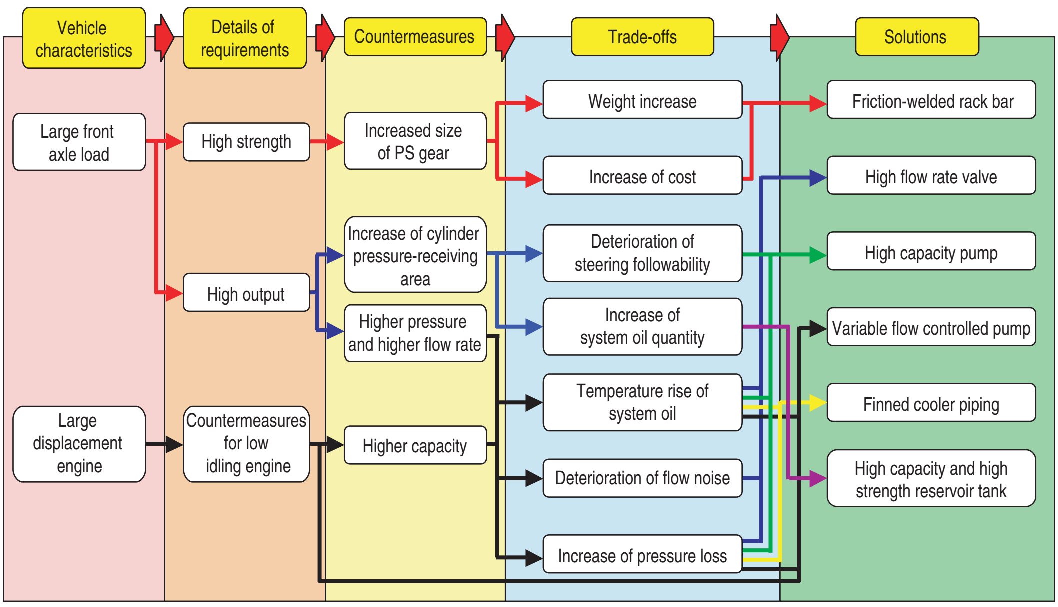

Fig. 3 Development flow

The material and manufacturing method generally used for rack bars are shown below.

· Material: Drawn carbon steel (solid material)
· Rack section: Cutting or forging
· Bypass hole: Gun drilling

However, large-vehicle PS gears require high strength, which in turn requires a large rack bar, but with the above-described general manufacturing method, there is a problem with weight. This may be solved by reducing the weight by increasing the diameter of the bypass hole. However, this causes increased cost due to increased time for the gun drilling process. Therefore, an enlarged bypass hole and elimination of gun drilling have been realized by friction welding of a solid section constituting the rack part and a hollow section constituting the rod part. As a result, reduced weight and cost has been achieved. **Figure 5** shows the difference between the conventional product and developed product. **Figure 6** shows the benefit of reduced weight, cost and metal chips provided by the developed product.

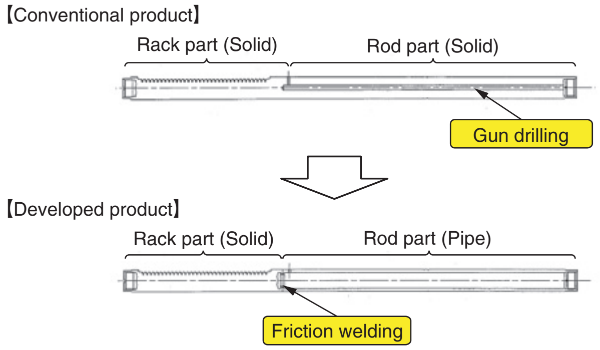

Fig. 5 Friction-welded rack bar

4. 2 High Flow Rate Valve

The term "valve" used herein means the component within a PS gear that controls the hydraulic assist operation. The valve is composed of a rotary valve having pressure holes through which hydraulic fluid enters control edges for controlling a flow path; and a control shaft having return holes (grooves) through which hydraulic fluid is discharged. The valve is structured so that the control edge sections narrow the flow path in accordance with the relative angle (valve operation angle) of components connected by the torsion bar to adjust the amount of fluid supplied to the cylinder. **Figure 7** shows the outline of the valve structure.

Main sizes of a conventional valve are shown below.

· Control edge length: 15mm
· Pressure hole of rotary valve: $\phi 3.0$
· Return hole of control shaft: $\phi 3.3$

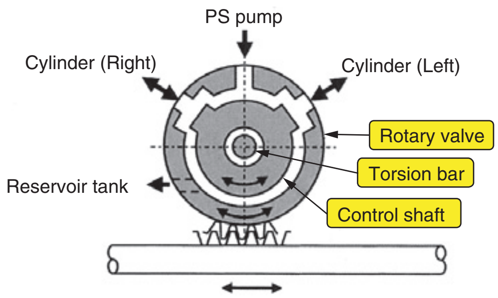

Fig. 7 Schematic structure of valve

However, a high flow rate is essential for large-vehicle PS gears, and it is clear that the above-described specifications will cause worsening flow noise and pressure loss compared to a conventional structure, and there is a high probability that the vehicle will experience problems with high noise and poor fuel efficiency. Thus, in order to handle the high pressure and high flow rate, the control edge length was increased to relieve sudden narrowing of the flow path and suppress deterioration of flow noise at the time of valve operation, and the rotary hole pressure holes were expanded and the control shaft return holes were changed to the shape of a return groove to reduce pressure loss caused by the expanded flow path and achieve smooth flow. **Figure 8** shows the difference between the conventional product and the developed product. **Figures 9** and **10** show the benefits of reduced flow noise and pressure loss in the developed product.

The reduced pressure loss also reduces heat generation of the PS pump, which reduces the oil temperature in the system. Regarding production, while the conventional rotary valve has a three-piece structure requiring the inner diameter to be machined, the developed rotary valve has

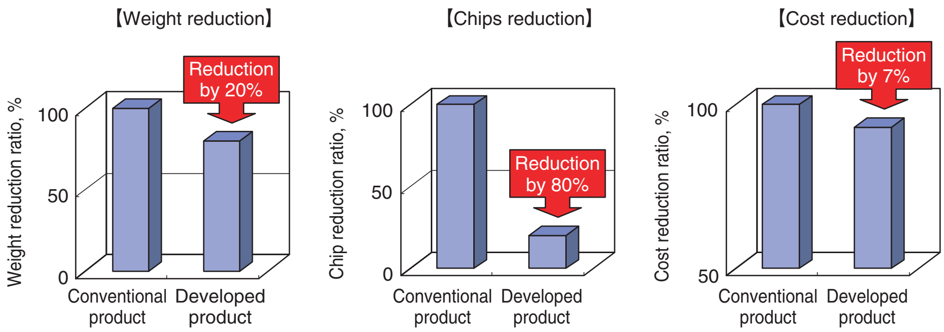

Fig. 6 Benefit of friction-welded rack bar

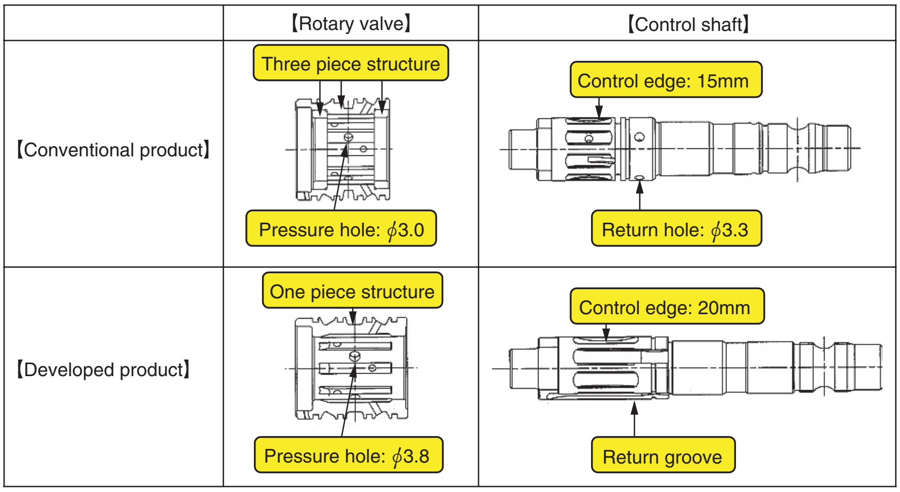

Fig. 8 High-flow-rate valve

a one-piece structure made by forging, and therefore the number of components is reduced because the sleeve is eliminated, reliability is improved because the possibility of sleeve disengagement from high pressure is eliminated, and the machining expense is reduced because of elimination of the inner diameter machining.

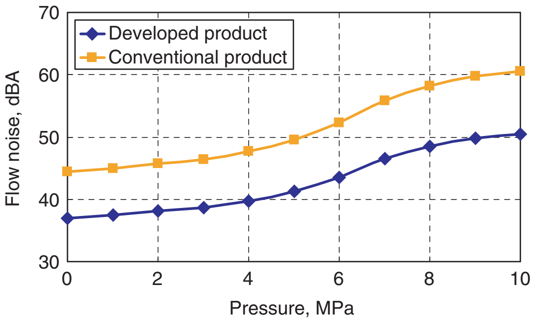

Fig. 9 Benefit (regarding flow noise) of high-flow-rate valve

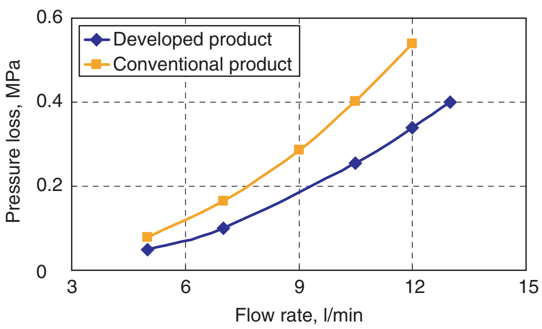

Fig. 10 Benefit (regarding pressure loss) of high-flow-rate valve

4. 3 High Capacity Pump

The PS pump is driven by the engine and supplies hydraulic fluid to the PS gear to enable power assist in the cylinder. A conventional PS pump has a theoretical discharge flow rate of 13 cm^3/rev or less and has no problem even when the hole diameter of the narrowest flow path of the discharge section is ϕ9. However, large-vehicle PS pumps must have high capacity, and with the discharge section shape of the conventional product, pressure loss increases, causing system fluid temperature rise and PS pump seizure. To prevent these problems, the developed product has an increased theoretical discharge flow rate of 15 cm^3/rev and a differently shaped discharge section to increase the opening area, thereby achieving reduced pressure loss. **Figure 11** shows the difference in PS pump discharge sections between the developed and conventional products. **Figure 12** shows the effect of pressure loss reduction of the developed pump.

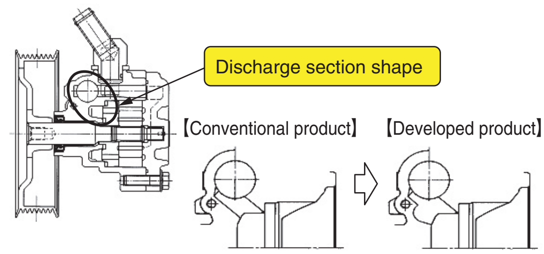

Fig. 11 Discharge section shape of high-capacity pump

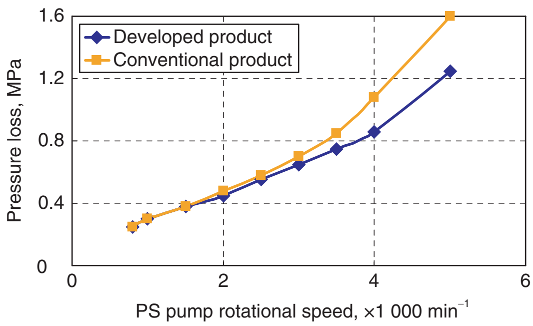

Fig. 12 Benefit (regarding pressure loss) of high-capacity pump

4. 4 Variable Flow Rate Pump

As described in section **3**, in the case of large vehicles improved fuel efficiency is sought and reduced PS pump power consumption is required. To realize this, the developed product has been equipped with a small electromagnetic valve so that the supply flow rate can be controlled based on the information from the ECU. Thus, the developed PS pump has reduced power consumption because the flow rate increases only when steering operation requires the supply of hydraulic fluid and decreases when the vehicle is being driven straight. **Figure 13** shows the structure of the variable flow controlled pump. **Figure 14** shows the effect of reduced power consumption of the developed product in each driving mode. As the reduced flow rate while the vehicle is being driven straight also reduces pressure loss, it is effective for lowering the system fluid temperature.

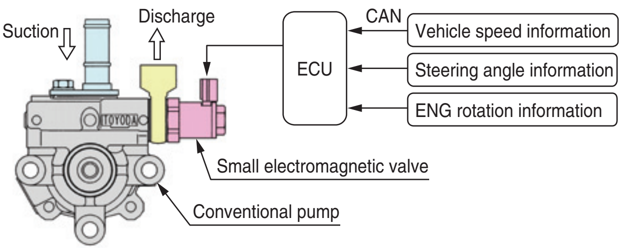

Fig. 13 Structure of variable flow controlled pump

4. 5 Finned Cooler Piping

"Cooler piping" is a section of PS piping located at the vehicle's front area in order to cool the system's hydraulic fluid. Generally cooler piping is formed by extending steel pipe with the same specifications as the return-path PS piping. However, the problem of fluid temperature rise in the system is caused when the general cooler piping as described above is used for large-vehicle PS pumps because this pump requires high capacity. To solve this, the diameter of the steel pipe of the developed pump has been expanded and a fin has been attached, resulting in increased heat radiation. **Figure 15** shows the difference between the developed and conventional products. **Figure 16** shows the heat radiation of the developed product.

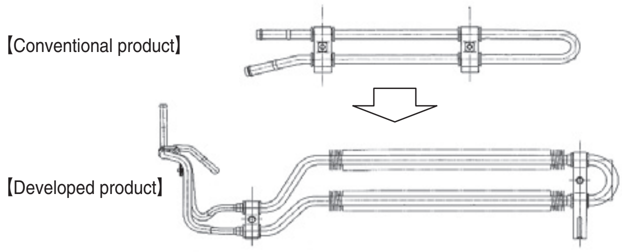

Fig. 15 Finned cooler piping

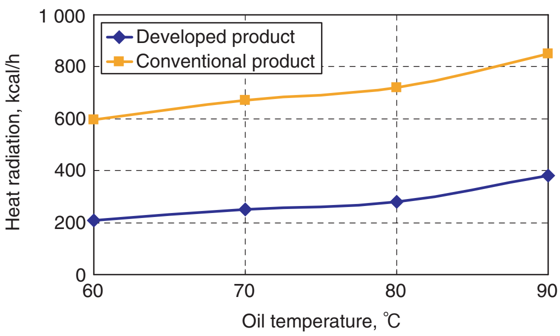

Fig. 16 Radiation effect of finned cooler piping

4. 6 High Capacity, High Strength Reservoir Tank

The reservoir tank has the function of compensating for the volume change of the system's hydraulic fluid caused by temperature change by storing a certain amount of the system's fluid inside the tank. However, in the case of a large-vehicle HPS system, the extended cylinder size and longer PS piping cause increased system fluid quantity and increased volume change, thus requiring a reservoir tank with higher capacity than that of the conventional system. Also, such a reservoir tank with higher capacity will possess higher weight, giving rise to reliability concerns related to damage in the case the tank is dropped. Particularly, the return pipe is welded to the reservoir tank body, and strength insufficiency can be a problem. To solve this, the reservoir tank capacity has been increased, and the return pipe welding method has been changed from vibration welding to laser welding to increase the welded area, thereby improving the return pipe's weld area reliability. **Figure 17** shows the difference between the developed and conventional products. **Figure 18** shows the improved weld strength of the developed product.

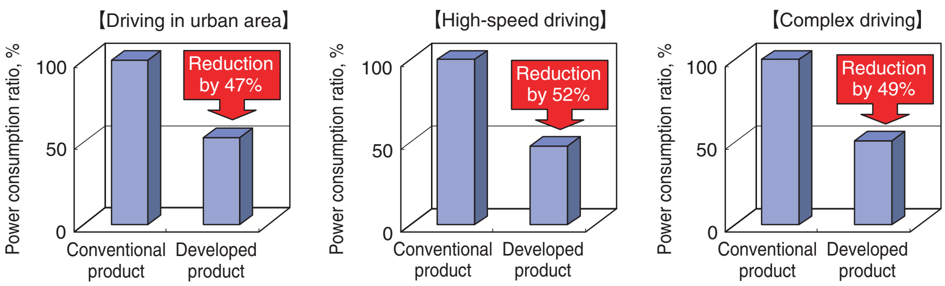

Fig. 14 Benefits (regarding power consumption) of variable flow controlled pump

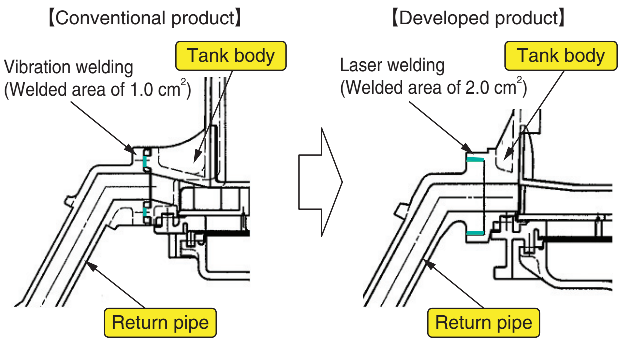

Fig. 17 High-capacity/strength reservoir tank

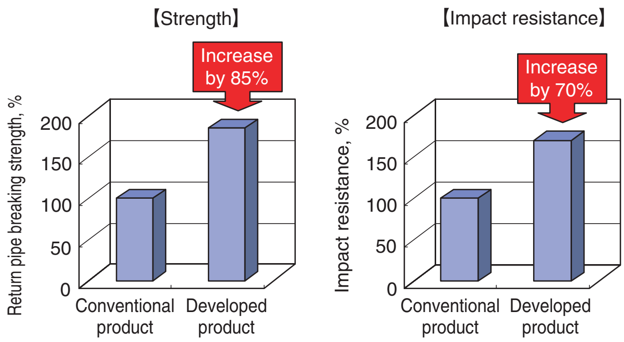

Fig. 18 Benefit of changing high-capacity/strength reservoir tank welding method

5. Conclusion

As described above, an HPS system optimal for large vehicles has been developed. JTEKT will endeavor to apply this system to other products as well and continue to work toward further improvement of HPS systems for large vehicles.



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